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ARTICLE *in* AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES · JUNE 2015

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ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Torque Direction and its Influence on Pinch Force in Loaded and Unloaded Conditions

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ARTICLE INFO

Article history:

Received 10 April 2015

Accepted 28 April 2015

Available online 22 June 2015

Keywords:

Torque direction Pinch force

Musculoskeletal disorders

Fingers Distal phalanges

Manual work

ABSTRACT

Background: Forceful pinch force exertions often cause hand-related injuries and cumulative trauma disorders, particularly when precision works such as twisting small knobs or screwdrivers are involved. In manual precision work that involve pinch grips, torque direction can be an underlying factor in the leverage and control of pinch forces. **Objective:** The aim of this study is to determine how torque direction influences pinch force, with a special emphasis on screw knobs that require pinching under loaded and unloaded conditions. **Results:** It was found that the influence of torque direction on pinch force is significant. In addition, the average pinch forces exerted in a clockwise motion were generally higher than those applied in a counterclockwise motion due to the skin friction from twisting the object in a clockwise torque direction, which flexes the distal phalanges and increases the normal force. **Conclusion:** This study enhances the knowledge on the influence of torque direction on pinch force, allowing designers to potentially design objects operated with pinch grips to be safer for various types of manual, sedentary and general tasks.

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To Cite This Article: Poh Kiat Ng, Adi Saptari, Kian Siong Jee, Yue Hang Tan., Torque Direction and its Influence on Pinch Force in Loaded and Unloaded Conditions. *Aust. J. Basic & Appl. Sci.*, 9(19): 74-79, 2015

INTRODUCTION

The use of hands and fingers are common in many manual activities such as twisting the handle of a screwdriver, turning a machine knob and pinching small threaded or unthreaded components (Seo and Armstrong, 2008; Seo *et al.*, 2008b; Shivers *et al.*, 2002). However, awkwardly positioned, high-force pinch grip exertions can lead to injuries and musculoskeletal disorders (Ellis *et al.*, 2004). High-force pinch force exertions can cause fatigue, discomfort and injury to the hand in industrial populations (Shivers *et al.*, 2002).

According to Rozmaryn (2013), finger-related injuries and musculoskeletal disorders are exceedingly common and constitute the largest percentage of hand injuries seen in the emergency room. These injuries can happen due to the mishandling of an equipment or when the pinch force exerted is more than the musculoskeletal system can handle (Kumar *et al.*, 2000; Seo, 2013). To further complicate matters, the use of unsuitable torque directions while inducing a grip can cause slippages to occur, leading to hand injuries (Seo *et al.*, 2007).

Researchers have posited that grip force increases with the inducement of clockwise torque direction compared to counterclockwise torque direction (Seo and Armstrong, 2006; Seo and

Armstrong, 2008; Seo *et al.*, 2007; Seo *et al.*, 2008a; Seo *et al.*, 2008b). These researchers discovered that the average fingertip force in a full handgrip was 90% greater for clockwise torque directions compared to counterclockwise torque directions ($p < 0.05$) (Seo *et al.*, 2007). The aforementioned literature presents the extensiveness of the studies that have been carried out on grip force and how torque direction influences grip force. However, there are still limited studies carried out on the influence of torque direction on pinch force. Hence, this study aims to determine the influence of torque direction on pinch force, with an emphasis on small apparatus that require pinching actions such as knobs.

Torque Directions:

Hand torque can be applied in two directions namely clockwise and counterclockwise torque directions. Clockwise torque direction is defined as the twisting movement of the hand towards the inner forearm direction, whereas the counterclockwise torque direction is defined as the twisting movement of the hand towards the outer forearm direction (Seo *et al.*, 2008a; Seo *et al.*, 2008b). Figure 1 shows an example of the clockwise and counterclockwise torque directions when turning a doorknob.

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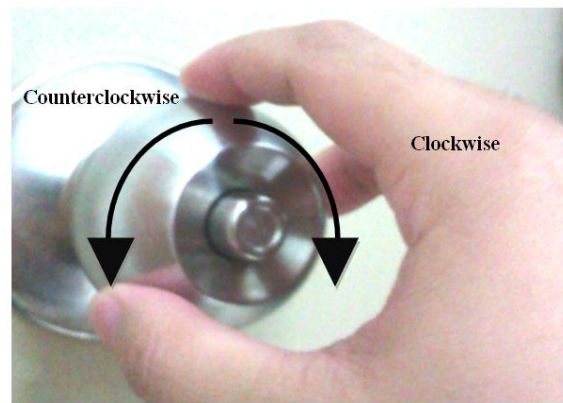


Fig. 1: The Clockwise and Counterclockwise Torque Direction.

According to Seo *et al.* (2008a), the clockwise torque direction is a movement of proximal-to-distal sense with respect to the fingers while the counterclockwise torque direction is a movement of proximal-to-distal sense with respect to the thumb. Torque is significantly affected by direction (Seo *et al.*, 2008a). A high amount of hand torque can be generated in a clockwise direction as compared to a counterclockwise direction (Ng *et al.*, 2014; Seo *et al.*, 2011) which can somehow be related with the action of unscrewing the lid of a jar or turning a doorknob (Ng *et al.*, 2014). According to Seo *et al.* (2007), clockwise torque direction can exert a greater force and greater torque than counterclockwise torque direction.

The clockwise rotations are used to tighten the grip while the counterclockwise rotations are used to loosen the grip. The normal forces with clockwise rotations are 19% greater than the normal forces with counterclockwise rotations. When the normal forces with clockwise rotations increase, the torque also increases. The torque is 22% greater for clockwise rotations than for counterclockwise rotations (Seo *et al.*, 2007). Seo *et al.* (2008b) also conducted a study to analyse the maximum torque exertions of individuals. The findings suggested that the average maximum torque, fingertip force, total normal force, grip force and thumb force of men on average was 2.2 times greater than that of women. The maximum torque for the high-friction rubber handle used in this experiment is 52% greater than the one generated by the lower-friction aluminium handle (Seo *et al.*, 2008b).

However, the results also depended on direction of the rotation. The clockwise rotation has greater torque, total normal force, grip force and fingertip force than the counterclockwise rotation. For the high friction rubber handle, the maximum torque for clockwise rotations is 53% greater than counterclockwise rotations. As for the aluminium handle, the maximum torque for clockwise rotations is 33% greater than counterclockwise rotations. This shows that maximum torque increases along with friction. High-friction handles produce greater torque

and grip force as compared to low-friction handles (Seo *et al.*, 2008b).

Screw Knobs:

One of the most common knobs used in most industries and daily living activities are screw knobs (Monroe, 2013). Most screw knobs are engineered and manufactured with reference to standardise requirements. Screw knobs are used in all sorts of common and industrial product designs, such as machines, hand tools, doors, furniture and electronic apparatus (Monroe, 2013).

Since screw knobs are widely used, there should be various types of shapes and sizes of knobs produced by a range of suppliers to accommodate different functions. Some examples of different knob shapes available are spherical, cylindrical, lobe, square, taper and wing/T-shaped knobs (Chestten, 2012; Supply, 2012).

The different shapes and sizes of screw knobs resemble those of other commonly used objects such as pipe valves, small screwdrivers, doorknobs, plastic bottle caps and control switches. Hence, screw knobs are selected to be used as the apparatus of this study in order to represent other types of commonly used objects in daily living and the industry.

Methodology:

In order to accurately measure the pinch force exerted on the screw knobs under a combination of factors, 3 Flexiforce sensors (from Tekscan Inc) were used for this experiment (refer to Figure 2). The sensors can be used to measure both static and dynamic forces (up to 1000 lb or 4446.22 N), and are thin enough to enable non-intrusive measurements.

The participation in the experiment is based on voluntary basis, where each participant is required to sign their consent to participate in the experiment before the experimentation can begin. Seo (2008) used a number of 12 participants in her study, which is a sufficient for the experiment to conduct accurate inferential statistical analyses. However, this study proposes to involve approximately 32 participants in

order to further improve the accuracy of the experiment results.

The protocol requires the participants to assume a seated posture. After taking a seat, 3 flexiforce sensors are attached to their thumb, fore finger and

middle finger. Figure 3 shows a demonstration of how the sensors will be attached according to the aforementioned procedures.



Fig. 2: Flexiforce Sensors.



Fig. 3: Attachment of Sensors to Fingers.

Each participant is required to pinch every knob with the 3 commonly used pinch techniques, as identified by Smith and Bengt (1985). The knobs are to be twisted using both clockwise and counterclockwise torque directions. Figure 4(a) presents an example of how a three-jaw chuck pinch

technique is applied, while Figure 4(b) shows how a pulp-2 pinch technique is applied. Figure 4(c) shows an example of how a lateral pinch technique is applied. Specific details on how the pinch force data are being measured and recorded are explained in the next section.



(a)



(b)



(c)

Fig. 4: The 3 Commonly Used Pinch Techniques (Smith and Bengt, 1985).

There are two different conditions prepared for the application of torque direction in the pinch activities, namely a loaded and unloaded condition. For the unloaded condition, a simple wooden structure is used to attach all the screw knobs (See Figure 5). The screw knobs are fitted into all the holes prepared based on the diameter of the screw knobs. This wooden structure fulfils the unloaded

condition because it does give any resistance whatsoever when the knobs are being pinched and turned in the structure.

For the loaded condition, actual doorknob mechanisms are embedded into a wooden structure (See Figure 6). The frontend of the doorknobs are modified to an adapter that allows the screw knobs to be attached. This basically allows the screw knobs to

be twisted with a loading effect. Thus, the loading effect for the screw knob is simulated by borrowing the principle of a normal doorknob mechanism. When the screw knobs are fitted into the holes of the adapter and turned, the doorknobs behind the adapter

create a counter force that simulates this loading effect. For this study, the analysis of variance (ANOVA) is used to determine the significance of the influence of torque direction on pinch force. Minitab version 16 is used for the ANOVA.



Fig. 5: Unloaded Wooden Structure.



Fig. 6: Loaded Wooden Structure with Knob Adapter and Indicators.

RESULTS AND DISCUSSION

For both loaded and unloaded conditions, the ANOVA test revealed the p -value to be 0.000 ($p < 0.05$). This implied that the influences of the torque directions on pinch force are significant. Figure 7(a) and Figure 7(b) show factorial plot results for the influence of torque direction on pinch force for the loaded and unloaded structure. For the loaded one in Figure 7(a), the force exerted in a clockwise motion (-1) appears to be higher than force exerted in a counterclockwise motion (1). The mean pinch force exerted with the clockwise torque direction (-1) is 79.6369g, which decreases by about 3.43% with the application of the counterclockwise direction (1) to a mean pinch force of 76.9056g. This result is similar for the unloaded one in Figure 7(b), where the pinch force exerted with the clockwise torque direction (-1) is 79.1335g, which decreases by about 3.44% with the application of the counterclockwise direction (1) to a mean pinch force of 76.4093g.

(Note: -1 refers to clockwise torque direction, 1 refers to counterclockwise torque direction):

Previous studies on hand grip force suggest that it is noticeable for greater torque to exist in

clockwise torque directions than counterclockwise torque directions (Seo *et al.*, 2007; Seo *et al.*, 2008a). According to Pheasant and O'Neill (1975), grip force will be greater when the torque is applied in the direction the fingertips point. This action is noticeable from twisting a screw driver or opening a jar, where greater torque is needed for clockwise torque direction than counterclockwise torque direction (Seo *et al.*, 2007; Seo *et al.*, 2008a). According to these researchers, this is because the skin friction produced by twisting an object in a clockwise torque direction can flex the distal phalanges and increase the normal force and torque (Seo *et al.*, 2007; Seo *et al.*, 2008a; Seo *et al.*, 2008b). These statements on grip force are consistent with the current findings on torque direction and pinch force.

Furthermore, according to a model that Seo *et al.* (2008a) developed, normal fingertip force (F_n) would increase with the application of the clockwise torque direction (-ve) and decrease with the application of the counterclockwise torque direction (+ve). The model is described as:

$$F_n = \frac{M_{DIP}}{X_n \pm X_f \mu_s} \dots\dots\dots (1)$$

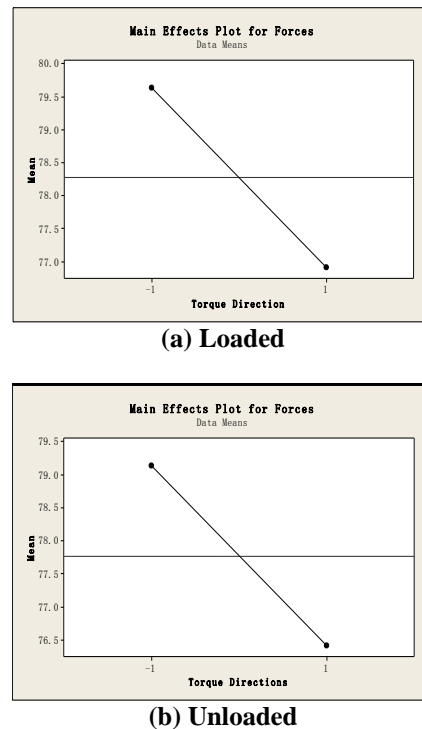


Fig. 7: Factorial Plot of Torque Direction.

(Note: “-” for clockwise torque, “+” for counterclockwise torque):

In the model, M_{DIP} is the moment for the DIP joint, X_f is the distance between the DIP joint and the friction force, F_n is the normal force on the fingertip, μ_s is the static coefficient of friction and X_n is the distance between the DIP joint and the normal force. The sign of the $X_f\mu_s$ term in the equation is negative

(-ve) for clockwise rotations and positive (+ve) for counterclockwise rotation. Based on this model by Seo *et al.* (2008b), it can be summarised that when a clockwise torque direction (-ve) is applied, the divisor in the equation decreases, hence increasing the overall quotient, which is the normal force. Figure 8 schematically describes this model.

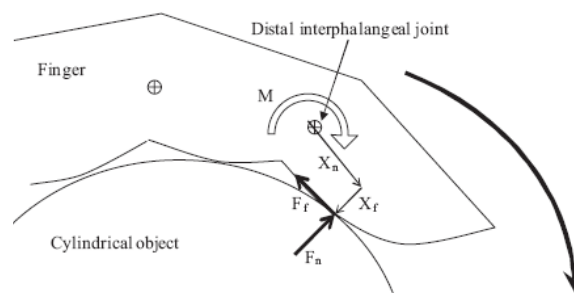


Fig. 8: A Schematic of the Model that Describes the DIP Joint Moment (Seo *et al.*, 2008b).

Normal forces with clockwise rotations are 19% greater than the normal forces with counterclockwise rotations (Seo *et al.*, 2007). When the normal forces with clockwise rotations increase, the torque also increases. The torque is 22% greater for clockwise rotations than for counterclockwise rotations (Seo *et al.*, 2007).

When conducting experiments on objects of different materials, Seo *et al.* (2008b) also found that the maximum torque for clockwise rotations is 53% greater than counterclockwise rotations for high friction rubber surfaces. Seo *et al.* (2008b) also found

that the maximum torque for clockwise rotations is 33% greater than counterclockwise rotations for aluminium surfaces.

Conclusion:

The influence of torque direction on pinch force is significant. This study concludes that the average pinch force exerted in a clockwise motion is generally higher than the average pinch force applied in a counterclockwise motion because the skin friction produced by turning the object in a clockwise torque direction can flex the distal phalanges and

increase the normal force.

This study enhances the knowledge of the influence of torque direction on pinch force. With these findings, designers can potentially design objects that are operated with pinch grips to be safer and more suitable for certain manual, sedentary or general tasks. This study can be beneficial to researchers, designers and engineers who are involved in the general design of not only screw knobs, but also ergonomic hand tools. These ergonomic hand tools can potentially improve the safety of manual work and eventually reduce the risk of hand-related injuries and musculoskeletal disorders.

Although further validation with other commonly used objects or manual tools may be required in order to verify if the similar outcomes can be posited in differing conditions, this study has provided preliminary evidence on the contributions of torque directions in pinch force, with hope the evidences in this study can be used for future design considerations to potentially reduce hand injuries and musculoskeletal disorders, and increase human performance and productivity.

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